

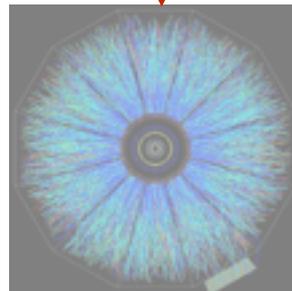
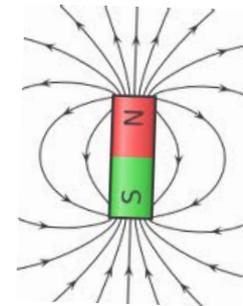
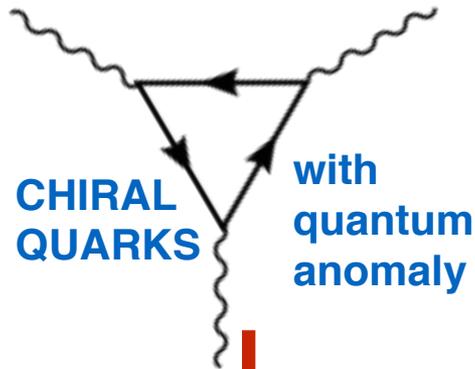
# Theory and Modeling for the Beam Energy Scan:

from Exploration to Discovery

RIKEN BNL Research Center Workshop  
February 26-27, 2015 at Brookhaven National Laboratory



## Discussion Session



*All available (only) in one UNIQUE LABORATORY: Heavy Ion Collisions*

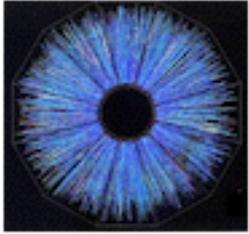
# OUTLINE

\* A Report from the Chirality Workshop:

“Chirality, Vorticity, and Magnetic Field in Heavy Ion Collisions”  
@ UCLA Jan 21–23, 2015

\* Physics of Chiral QGP via Anomalous Effects in the  
Perspective of Beam Energy Scan Physics

# A SUCCESSFUL MEETING



## QCD Chirality Workshop 2015

*Organizers: Huan Zhong Huang, Mei Huang, Dmitri Kharzeev, Jinfeng Liao, Sergei Voloshin, Gang Wang*

- \* 43 attendees from all over the world
- \* 31 talks & 1 discussion session covering all aspects of the topic
- \* Continuing the theme of physics of a series of topical meetings
  - 2014 Workshop on “QCD Vacuum and Matter under Strong Magnetic Field”, organized by Huang, Huang, Hou, Wang, Zong.
  - 2014 Simons Workshop “Quantum Anomalies and Hydrodynamics”, organized by Herzog, Jensen, Kharzeev, Ryu, Son.
  - RBRC Workshop “CPODD2012”, organized by Kharzeev, Liao, Shuryak, Yee
  - RBRC Workshop “CPODD2010”, organized by Deshpande, Fukushima, Kharzeev, Voloshin, Warringa

# A STRONG COMMUNITY

- \* US community

- \* Theory: BNL, LBNL

- Stony Brook, MIT, U Chicago, UIC, IU, ...

- \* Experiment (RHIC & LHC, STAR/PHENIX/ALICE/ATLAS):

- BNL, LBNL

- UCLA, Wayne State, Stony Brook, ...

- \* International community

- China, India, Japan, Canada, Europe, ...

*This community is well reflected by the program and attendees of the Chirality Workshop.*

***This is really a growing community nurtured by  
BOTH THEORISTS AND EXPERIMENTALISTS!***



# A REMARKABLE LIST OF ACHIEVEMENTS

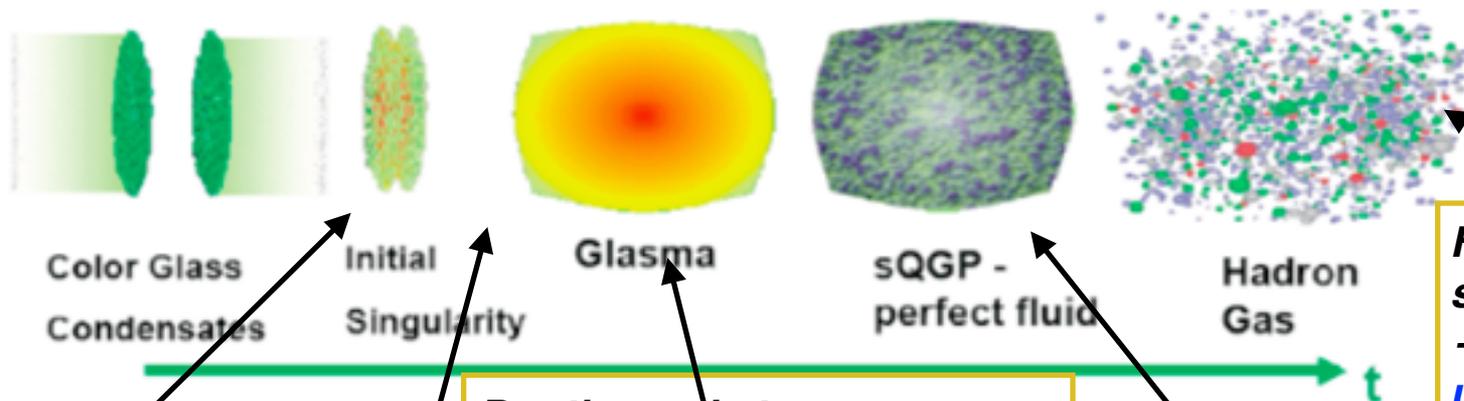
- \* Theoretical framework is (nearly) matured:
  - \* Anomalous Hydrodynamics (in/near equilibrium)
  - \* Chiral Kinetic Theory (out of equilibrium)
- \* Several anomalous transport effects were proposed, and studied to varied degrees of sophistication, with a number of experimental observables suggested
  - \* CME, CSE; CVE, aCVE; CESE; EM emissions; ...
  - \* Collective excitations: CMW, CEW, CVW, ...
- \* We now have a wealth of experimental data:
  - \* RHIC, RHIC BES, LHC, RHIC UU & CuAu(?)
  - \* conserved-charge-dependent correlations/flows for hadrons

*This list is well reflected by the program and attendees of the Chirality Workshop.*

# A “CRITICAL POINT”

*We are at a “critical point” for transitioning from the phase of “new ideas, qualitative estimates, rough trends in exp. data” toward the phase of “quantitative modelings, and experimental validations”.*

*We are ready to take that up!*



**Initial conditions:  
for CHARGES!!!  
(flavor-wise & Axial)  
—> need theory/model**

**Pre-thermal stage:  
important if all effects  
occur early!  
—> need pre-thermal model  
(combined efforts with  
thermalization studies?)**

**Driving “forces”  
(E,B fields, vorticity)  
—> need precise implementation  
of space and time dependence (M-V-C-A-Hydro)**

**Hydrodynamic  
evolution:  
—> need to implement  
“in-flight NOISE” of  
C and A charges  
(hydro with C/A  
fluctuations)**

**Hadronic  
stage:  
—> need to  
understand  
its impact on  
observables**

*Such needs of future efforts are well reflected by the vibrant discussions at the Chirality Workshop.*

# A TIMELY CALL

**U. S. Department of Energy  
Office of Science  
Nuclear Physics**

**Topical Collaborations in Nuclear Theory  
Funding Opportunity Number: DE-FOA-0001269  
Announcement Type: Initial  
CFDA Number: 81.049**

|                                   |  |
|-----------------------------------|--|
| <b>Issue Date:</b>                | <b>01/14/2015</b>                      |
| <b>Letter of Intent Due Date:</b> | <b>03/20/2015 at 5 PM Eastern Time</b> |
| <b>Pre-Application Due Date:</b>  | <b>Not Applicable</b>                  |
| <b>Application Due Date:</b>      | <b>04/30/2015 at 5 PM Eastern Time</b> |

- \* *Chiral QGP Physics: a perfect case for a focused T.C. effort***
- \* *Natural integration with the Beam Energy Scan program***

# IN THE PERSPECTIVE OF BES

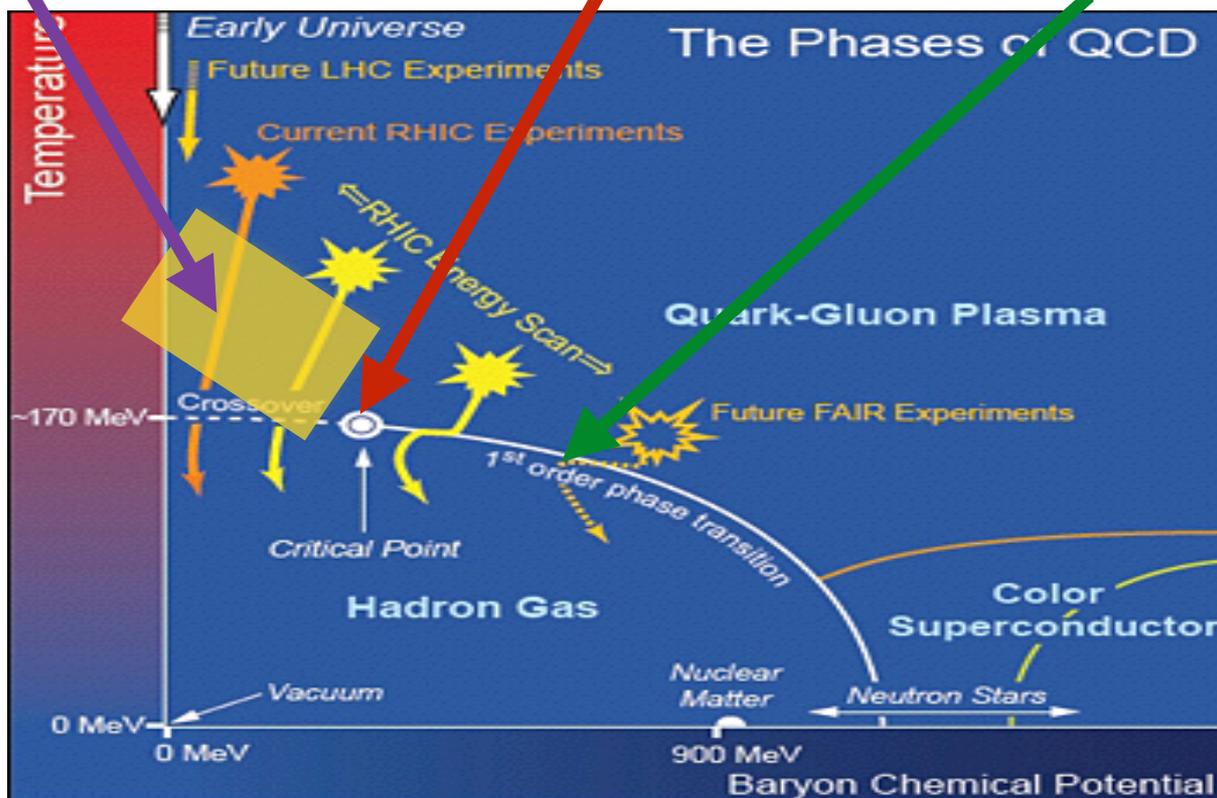
*The fundamental physics goal:  
understanding the CHIRAL SYMMETRY of QCD*

**A Chiral-Symmetric QGP**

*lattice validated;  
exp. signals?*

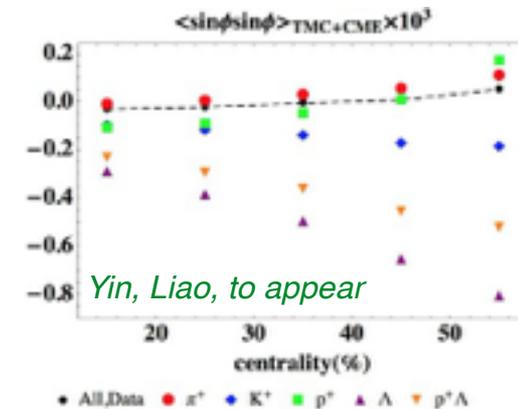
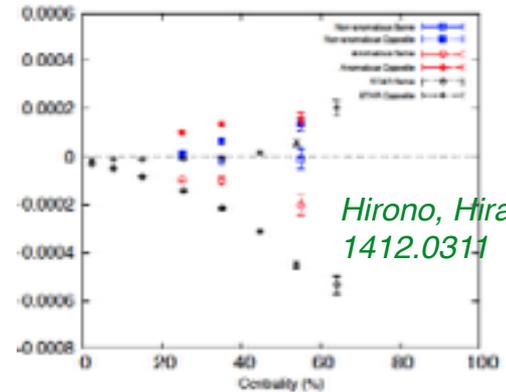
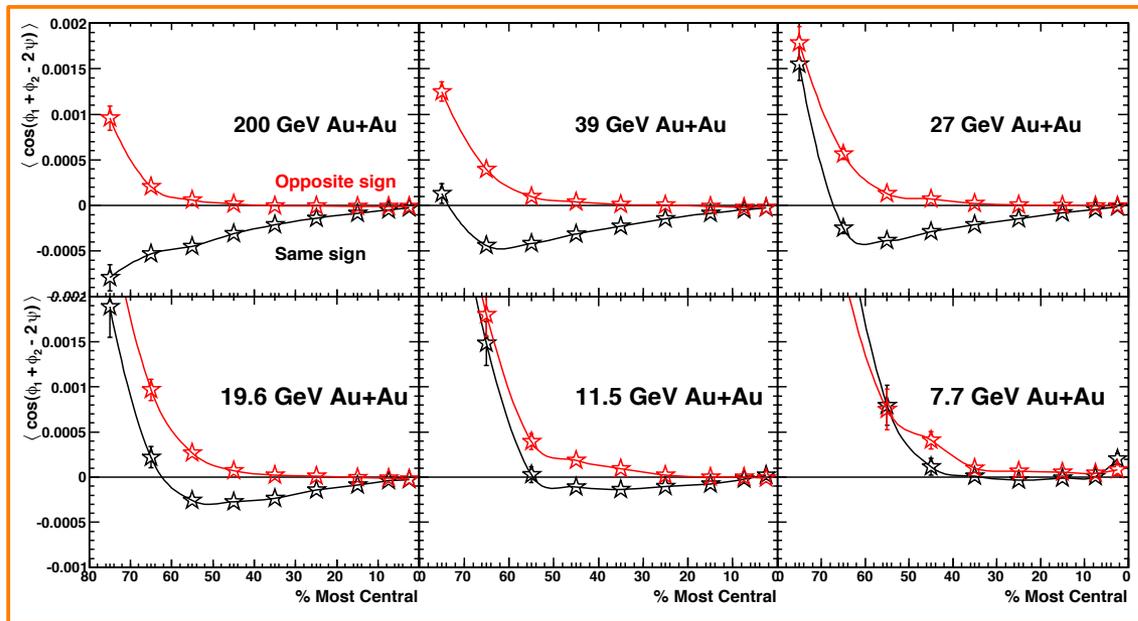
**A Chiral-Critical Point**

**A Chiral-Breaking Transition**



- \* ***It is only with ALL THESE that we can achieve our goal.***
- \* ***Anomalous transport effects manifest a CHIRAL QGP.***

# EXAMPLE: CME & CHARGE-DEPENDENT AZIMUTHAL CORRELATIONS

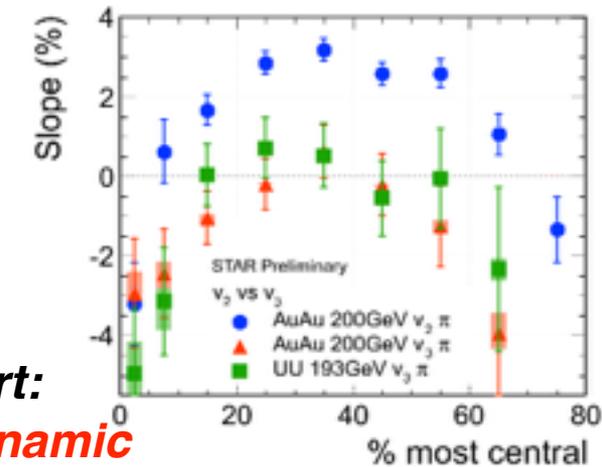
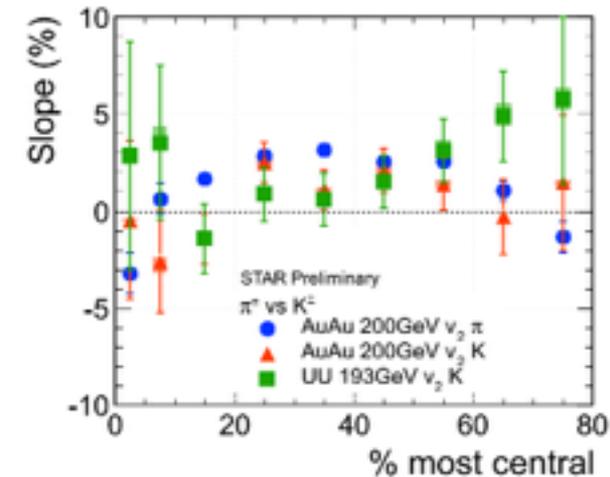
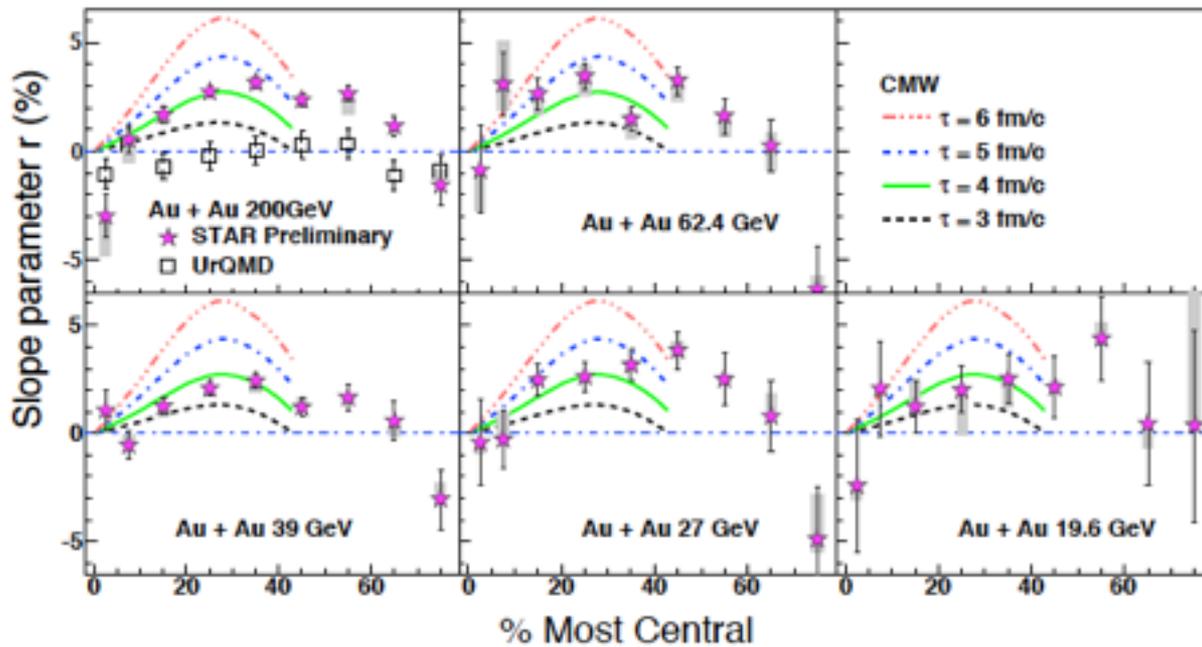


- \* Highly interesting dynamical change with BES
- \* Lacking a quantitative interpretations

\* **A possible Milestone to be achieved via T.C. effort:**

**By implementing quantitative chiral magneto-hydrodynamic simulations and by evaluating background effects within the same framework, draw a definitive conclusion on the occurrence of CME as well as its disappearance with collisional beam energy.**

# EXAMPLE: CMW & CHARGE-DEPENDENT AZIMUTHAL FLOWS

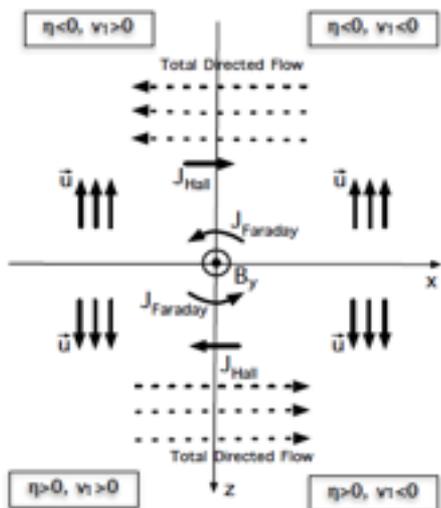


- \* Highly encouraging patterns from data
- \* Needing quantitative th/exp comparison

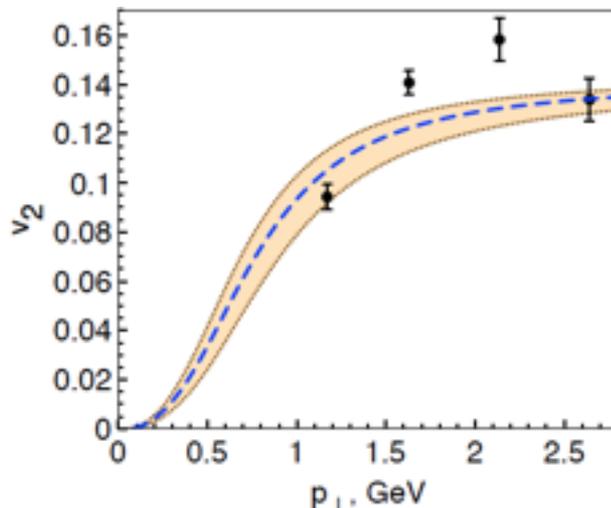
\* **A possible Milestone to be achieved via T.C. effort:**

**By implementing quantitative chiral magneto-hydrodynamic simulations and by realistic modeling of charge initial conditions, systematically quantify the signal of CMW, the CMW velocity, as well as their dependence on collisional beam energy.**

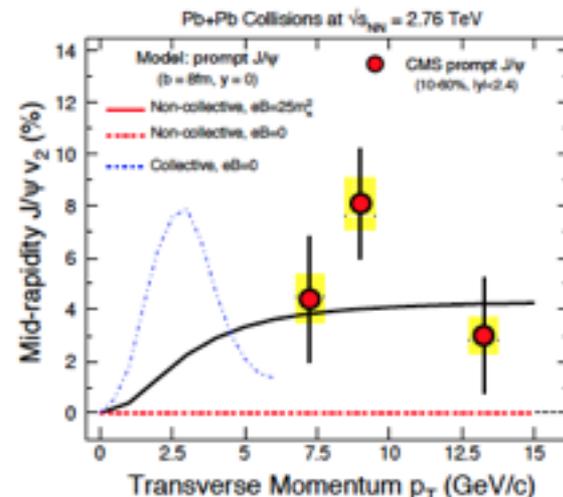
# EXAMPLE: EXTREME QED PHYSICS



*B-induced nontrivial  $v_1$  patterns*  
 Gursoy, Kharzeev, Rajagopal,  
 arXiv:1401.3805



*B-induced photon  $v_2$*   
 Barsar, Kharzeev, Skokov,  
 arXiv:1206.1334

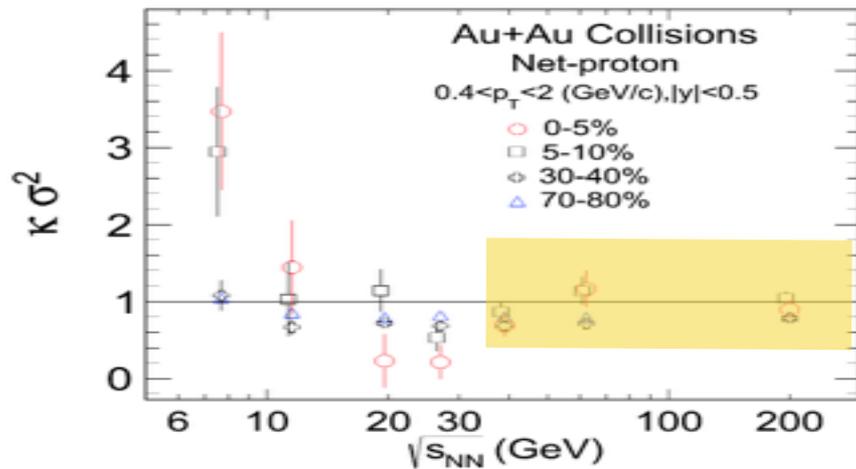


*B-induced  $J/\Psi$   $v_2$*   
 Guo, Shi, Zhuang, Xu  
 arXiv:1502.04407

\* A direct access to the strongest B field of our knowledge, is highly desired.

\* **A possible Milestone to be achieved via T.C. effort:**  
**By utilizing magneto-hydrodynamic simulations and by studying a set of sensitive observables, provide a way for direct experimental determination of the strongest magnetic field ever and how it changes with collisional beam energy.**

# AN INTEGRATED T.C. EFFORT



|            | lower<br>root{s}        | higher<br>root{s} |
|------------|-------------------------|-------------------|
| central    | CEP & 1st<br>transition |                   |
| peripheral |                         | Chiral<br>QGP     |

\* An (incomplete) to-do-list for anomalous effects

\* Framework: anomalous v-hydro + densities + dynamical B,V + noise

\* Physical model(s) for: initial conditions; pre-thermal evolution

\* Simulation code: integrating these components

\* Careful evaluations of background effects (e.g. hadronic stage)

\* A set of key predictions to be compared with data

— *A well-defined set of problems, allowing a “factorized” approach*

— *sharing the same needs of data-validated bulk dynamics with all BES physics*

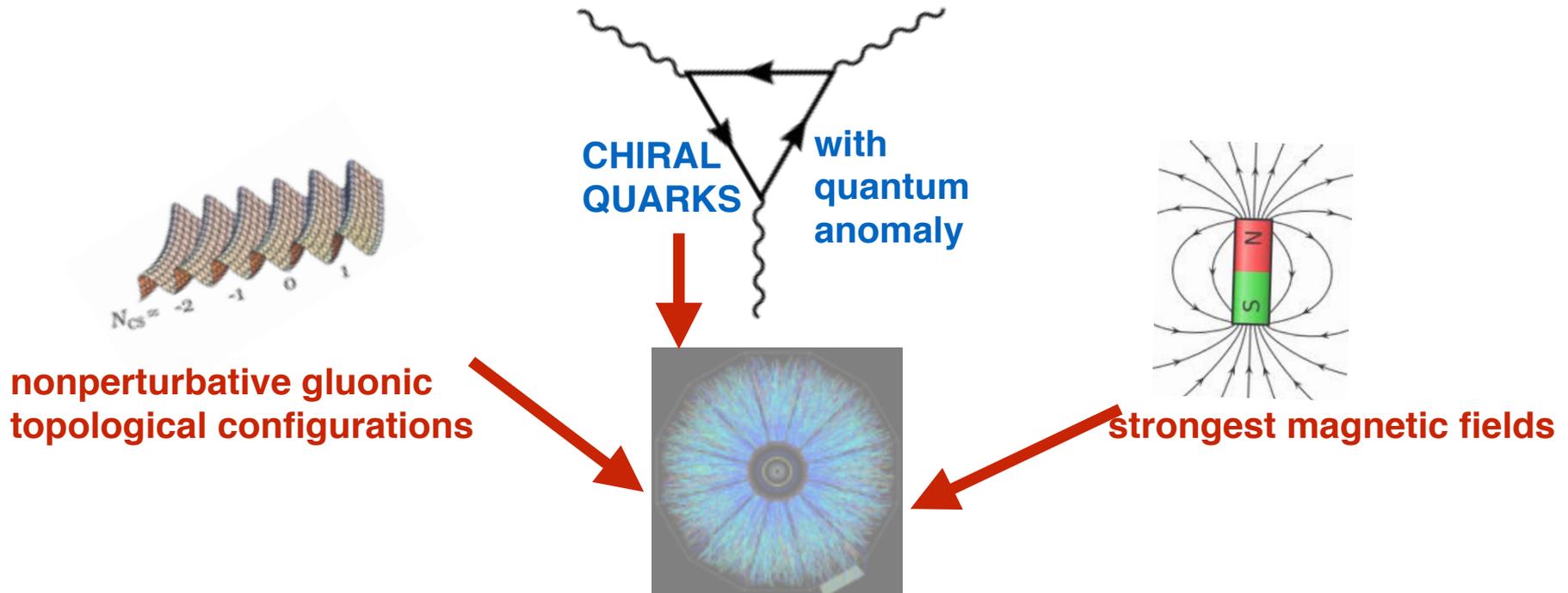
— *requiring adequate, stable and longer-term support for focused and collaborative efforts through a Topical Collaboration !*

# LET US DO IT!

## A Major Deliverable:

A Chiral Magneto-Hydrodynamics (CMHD) simulation code, applicable at finite baryon density and taking into account dynamical magnetic fields, and made publicly available.

*It will be a necessary and powerful tool, for exploring the ON and OFF for a chiral QGP as well as for search of CEP, and other BES physics!*



*All available (only) in one UNIQUE LABORATORY: Heavy Ion Collisions*